



**University of  
Zurich**<sup>UZH</sup>

**Zurich Open Repository and  
Archive**

University of Zurich  
University Library  
Strickhofstrasse 39  
CH-8057 Zurich  
[www.zora.uzh.ch](http://www.zora.uzh.ch)

---

Year: 2020

---

## **Age-related participation and performance trends of children and adolescents in ultramarathon running**

Scheer, Volker ; Di Gangi, Stefania ; Villiger, Elias ; Nikolaidis, Pantelis T ; Rosemann, Thomas ; Knechtle, Beat

**Abstract:** Participation and performance trends as well as the performance differences among sexes in ultra-endurance running have been well described in the adult population; however, less information on such trends existed in youth ultramarathoners. The aim of the present study was to investigate the age-related participation and performance trends of children and adolescent ultramarathoner runners. Data on runners, younger than 19 years of age, competing from 1960 to 2018 in distance-limited ultramarathons of 50 km, 100 km, 50 miles and 100 miles, were analysed. During this period, the number of ultramarathon participation increased, most notably among boys, most runners originated from Europe, and the 50- and 100-km race distances were the most popular. Overall, male runners were faster than female runners, except in the case of European and Oceanian origin, where girls were faster over the 50-km race. The fastest male runners originated from Africa and the fastest girls from Oceania, and the average running speed has largely decreased for both sexes over calendar years. In summary, this study was the first to report details on participation and performance trends in youth ultramarathoners competing in distance-limited ultramarathons.

DOI: <https://doi.org/10.1080/15438627.2020.1781124>

Posted at the Zurich Open Repository and Archive, University of Zurich

ZORA URL: <https://doi.org/10.5167/uzh-188235>

Journal Article

Accepted Version

Originally published at:

Scheer, Volker; Di Gangi, Stefania; Villiger, Elias; Nikolaidis, Pantelis T; Rosemann, Thomas; Knechtle, Beat (2020). Age-related participation and performance trends of children and adolescents in ultramarathon running. *Research in Sports Medicine*, 28(4):507-517.

DOI: <https://doi.org/10.1080/15438627.2020.1781124>

# Age-related participation and performance trends of children and adolescents in ultramarathon running

Volker Scheer <sup>1,2</sup>, Stefania Di Gangi <sup>3</sup>, Elias Villiger <sup>3</sup>,  
Pantelis T. Nikolaidis <sup>4</sup>, Thomas Rosemann <sup>3</sup>, Beat Knechtle <sup>3,5\*</sup>

<sup>1</sup> Ultra Sports Science Foundation, Pierre-Bénite, France

<sup>2</sup>Health Science Department, Universidad a Distancia de Madrid (UDIMA), Madrid, Spain

<sup>3</sup>Institute of Primary Care, University of Zurich

<sup>4</sup>Exercise Physiology Laboratory, Nikaia, Greece

<sup>5</sup>Medbase St. Gallen Am Vadianplatz, St. Gallen, Switzerland

Volker Scheer - volkerscheer@yahoo.com

Stefania Di Gangi - Stefania.DiGangi@usz.ch

Elias Villiger - evilliger@gmail.com

Pantelis Theodoros Nikolaidis – pademil@hotmail.com

Thomas Rosemann – thomas.rosemann@usz.ch

Beat Knechtle – beat.knechtle@hispeed.ch

## \* Correspondence:

Prof. Dr. med. Beat Knechtle

Facharzt FMH für Allgemeinmedizin

Medbase St. Gallen Am Vadianplatz

Vadianstrasse 26

9001 St. Gallen

Switzerland

Telefon +41 (0) 71 226 93 00

Telefax +41 (0) 71 226 93 01

E-Mail beat.knechtle@hispeed.ch

51    **ABSTRACT**

52    Participation and performance trends as well as the performance differences among sexes in  
53    ultra-endurance running have been well described in the adult population; however, less  
54    information on such trends existed in youth ultramarathoners. The aim of the present study  
55    was to investigate the age-related participation and performance trends of children and  
56    adolescent ultramarathoner runners. Data on runners, younger than 19 years of age,  
57    competing from 1960 to 2018 in distance-limited ultramarathons of 50 km, 100 km, 50 miles  
58    and 100 miles, were analysed. During this period, the number of ultramarathon participation  
59    increased, most notably among boys, most runners originated from Europe, and the 50- and  
60    100-km race distances were the most popular. Overall, male runners were faster than female  
61    runners, except in the case of European and Oceanian origin, where girls were faster over the  
62    50-km race. The fastest male runners originated from Africa and the fastest girls from  
63    Oceania, and the average running speed has largely decreased for both sexes over calendar  
64    years. In summary, this study was the first to report details on participation and performance  
65    trends in youth ultramarathoners competing in distance-limited ultramarathons.

66    **Key words:** boy, girl, ultra-endurance, running, ultramarathon

67

68

69

70

71

72

73

74

75

## 76 INTRODUCTION

77 The participation in ultra-endurance activities has increased over the last few decades (Costa,  
78 Knechtle, Tarnopolsky, & Hoffman, 2019; Scheer, 2019). This trend included ultra-endurance  
79 running events with distances over the traditional marathon distance of 42.195km (Scheer &  
80 Murray, 2015). Participation and performance trends (da Fonseca-Engelhardt et al., 2013;  
81 Knechtle, Rüst, Rosemann, & Lepers, 2012) as well as the performance differences among  
82 sexes (in half-marathon, marathon and ultra-marathon) were well described in the adult  
83 population (Eichenberger, Knechtle, Rust, Rosemann, & Lepers, 2012; Knechtle &  
84 Nikolaidis, 2018a; Nikolaidis, Cuk, Clemente-Suárez, Villiger, & Knechtle, 2020).  
85 Performance trends of master athletes in ultramarathons have also been studied (Zingg, Rüst,  
86 Lepers, Rosemann, & Knechtle, 2013).

87 Data on childhood participation in ultra-endurance events are limited, but one study described  
88 an exponential increase in participation over the last 20 years (Scheer & Hoffman, 2019). The  
89 age group with the greatest number of finishers was the 16-18-year olds, but even children as  
90 young as 10 years old finished ultra-endurance events (Scheer & Hoffman, 2019). The most  
91 popular running distances included the 50km and 100km events with the majority of finishers  
92 being boys (Scheer & Hoffman, 2019).

93 Performance and performance trends in this young ultra-endurance population would be of  
94 interest, especially as it could aid fitness trainers and coaches working with young athletes to  
95 set optimal training goals. Therefore, the aim of the current study was to fill this gap by  
96 investigating performance times and trends at different ultra-endurance distances, age groups  
97 and countries of origin.

98

99

## MATERIALS AND METHODS

### *Ethics approval*

The study was approved by medical council (Ärzttekammer Westfalen Lippe, Germany) and the University of Münster, Germany (Chairperson Prof. Berdel, protocol number 2018-304-f-S), and all procedures adhered to the principles derived from the Declaration of Helsinki.

### *Data sampling and data analysis*

All data were accessed in the website of DUV (Deutsche Ultramarathon Vereinigung), where all race results of ultramarathons were recorded (<https://statistik.d-u-v.org/index.php>).

A computer script was written to retrieve a list for every event recorded on the website. Each event's web page was then read by the script to extract the complete data table available. The script compiled all that data into one large excel file which was our starting point for further manual filtering of relevant information.

We analysed data of distance-limited races (50 km, 50 miles, 100 km and 100 miles) from 1960 to 2018. The following variables were analysed: year of race, race distance, name of the race, race time or performance (h:min:s), name of athlete, year of birth, nationality and sex of athlete. Running speed (km/h) was calculated from the time and distance variables. Age was derived by subtracting the year of birth from the year when the race was held. Continent variable was defined from the nationality of the athletes. Inclusion criterion was that participants finished either a 50-km, 50-miles, 100-km or 100-mile race between 1960 and 2018, and were under the age of 19. Data from participants that were implausible (e.g., age under 13 years) were excluded from further analyses.

## 122 *Statistical analysis*

123 **Running speed (km/h) was the main outcome measure.** Information of all races **concerning**  
124 number of observations, mean (SD) and minimum and maximum of speed (km/h) was  
125 provided (**Table 1**). **Distance**-limited races of 100 miles **were excluded from the main**  
126 **analyses due** to insufficient data (<100 observations). Descriptive statistics were presented as  
127 means **and SD (standard** deviations) by sex, age groups, continents and time groups. The age  
128 groups were 10–13, 14–15, 16–17 and 18 years. Continent groups, with reference to the  
129 nationality of the athletes, were: Africa, Asia, Central-South America, Europe, North-  
130 America, Oceania. When the number of observations of each continent group, within each  
131 race, was not greater than 10, continents were grouped together into other continents. To  
132 show performance by period of time, calendar year of the race was grouped into time-periods  
133 of 10 years. Age and calendar **year were** considered as continuous **variables in** 1-year  
134 intervals, when defined as predictor variables for ultramarathon speed. In fact, non-linear  
135 regression mixed models, with basis splines (BS), were performed to examine the time trend  
136 together with the effects of sex, age and continent on the speed time of each distance race.  
137 The mixed models were used to correct for repeated measurements within runners (clusters)  
138 through the random effects of intercepts. The statistical models were specified as follows:  
  
139 Ultramarathon running speed (Y) ~ [Fixed effects (X) = BS(Year, df = 3) + BS(Age, df = 3) +  
140 continent + sex\*continent + [random effects of intercept=runners]  
  
141 where BS(Year, df=3) and BS(Age, df = 3) **were** 3 degrees of freedom (df) basis splines  
142 changing with calendar year and age, respectively; sex\*continent denote the sex-continent  
143 interaction term. Different analyses were performed, one for each distance (50 km, 50 miles,  
144 100 km). The interaction term sex-continent was significant and considered only in the 50km  
145 analysis. In the 100 km analysis, since the fit was better, a linear term on age, instead of the

relative spline term, was considered. Results of the regression models were presented as estimates and standard errors. Statistical significance was defined as  $p < 0.05$ . All statistical analyses were carried out with R, R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>. The R packages ggplot2, lme4, and lmerTest were used, respectively, for data visualization and for the mixed models.

## RESULTS

A total of 2,083 records on 1,496 different finishers with information on age were retrieved from the database on 50-km ultramarathon races between 1977 and 2018. For 100 km race, a total of 2,057 records on 1815 different finishers was available for the period between 1960 and 2018. In 50-/100-km races, the number of women was 289 (19.3%)/ 112 (6.2%) with 399 (19.2% of the total observations) / 132 (6.4% of the total observations) records, and the number of men was 1,207 (80.7%) / 1,703 (93.8%) with 1,684 (80.8%)/1925 (93.6%) records.

In 50 km and 50 miles, the majority of finishers were 16-17 years old ( $n=823$ , 39.5%;  $n=404$ , 42.2%, respectively), followed by 18 years old ( $n=795$ , 38.2%;  $n=359$ , 37.5%). In 100 km, the vast majority of finishers were 18 years old,  $n=1,458$  (70.9%). In 50 km and 50 miles, the vast majority of finishers came from North-America,  $n=1,739$  (83.5%) and  $n=856$  (89.4%) respectively.

Most finishers that participated in 100 km races came from Europe 1,903 (92.5%). In distance races, the highest number of participations occurred during the years between 2010-2018, especially in 50 km with 1,534 (73.6%) and in 50 miles 451 (47.1%). Instead, in 100 km, 80.5% of observations were recorded before 1990. The number of observations and the average performance by sex, age groups and continent were reported in Table 2. Moreover, the number of observations and the average performance by time groups was reported in Table 3. In Figure 1, participation (%) and average performances (km/h) for 50 km/h distance race were shown by nationality. Accordingly, figures for the other distance races were reported as supplemental material (Figures S1-S2). The results of the statistical models, as described in the methods section, were reported as supplemental material (Table S1). Boys were significantly faster than girls in all races. The largest sex differences were observed in the 50 km and 50 miles races, where boys were on average 0.76 km/h ( $SE=0.12$ ,  $p<0.001$ ) and



0.78 km/h (SE=0.15,  $p<0.001$ ) faster than girls, respectively. Compared to North-America, European children and adolescents were significantly faster in 50km races (1.69 km/h (SE=0.42,  $p<0.001$ )) but slower in 50 miles races (0.70 km/h (SE=0.30,  $p<0.05$ )) and faster in 100km races (1.50 km/h (SE=0.21,  $p<0.001$ )). Compared to North-America, runners from other continents (*i.e.* Africa, Central-South America and Oceania) were on average faster in 100km races (1.94 km/h (SE=0.53)). In 50 km races, the Sex\*Continent interaction showed that boys from Africa were significantly faster (on average 3.77 km/h (SE=1.82)), depicting the largest distance between the fitted curves in boys and girls for African finishers, although numbers were small. All the effects presented in Table S1 were shown graphically for 50 km/h distance race in Figures 2 and Figure S3 and for the other distance races in Figures S4-S7.

Running speed increased across age groups in 50 km (Figure 2) and 50 miles (Figure S4). In 100 km, age had no significant effect (Figure S6). Across calendar years, running speed decreased in both girls and boys for all nationalities in 50 km (Figure S3). In 50-miles (Figure S5) and 100-km races (Figure S7), running speed increased and then decreased across calendar years.

## DISCUSSION

The aim of the present study was to investigate the age-related participation and performance trends of children and adolescent ultramarathoner runners. The main findings were (i) the number of ultramarathon participation increases over time, most notably among boys (ii) 50 and 100km race distances were the most popular, with most runners originating from Europe (iii) boys were generally faster than girls, with the fastest male runners originating from Africa, and fastest girls from Oceania (iv) European girls and girls from Oceania were faster over the 50 km distance compared to boys from the same continent, and (v) the average running speed over calendar years largely decreased for both sexes.

### *Participation trends by distance*

An exponential increase in participation numbers among male ultramarathoners was observed since the 2000s, whereas there was a more gradual, linear increase starting mostly over the last decade in females. The most popular running distances were those of 50 km and 100 km, followed by 50 miles and 100 miles races, although participation in the latter two were significantly less. There was no female participation in the 50 km until the 1980s. This observation confirmed previous findings in young ultramarathon runners (Scheer & Hoffman, 2018). Similar participation trends might be observed in the adult population, with the 50km distance being the most popular running distance (Scheer, 2019). The increased participation of young athletes in ultra-marathon events might be attributed to the overall increased participation in ultra-marathon races observed in adult runners (Knechtle & Nikolaidis, 2018a).

The majority of finishers belonged to the older age groups (16-18 years of age) and were mostly male. In 18-year old boys, the 100 km distance was the most popular, followed by 50 km and 50 miles. In girls, the 50 km distance was the most popular distance, and among boys

ranging from 10-17 years of age. The findings in line with previously published data (Scheer & Hoffman, 2018).

### ***Participation trends by continent***

Most ultramarathon runners originated from Europe, with the 100 km distance being the most popular one. Similar findings in adult ultramarathon runners confirmed this trend, as most 100 km race finishers came from Europe (Cejka et al., 2014; Knechtle, Nikolaidis, & Valeri, 2018). Runners from North America were the second largest group, with a preference for the 50 km distance, for both boys and girls alike. Participation numbers from other continents were low, although the 50 km distance was the most popular among them. The 100 km were mostly run by European boys and girls. The 50 miles were almost exclusively run by athletes from North America. This may hardly be surprising as 50-mile races were rarely held in Europe. This was also shown in master ultramarathoners, where most 50-mile runners originated from the USA (Waldvogel, Nikolaidis, Di Gangi, Rosemann, & Knechtle, 2019).

### ***Performance analysis: Running speed by distance, age and calendar year***

Running speed increased across age groups in 50 km and 50 miles races. In 100 km races, however, age had no significant effect. In other terms, boys and girls improved their running performance with increasing age with the exception of the 100 km ultramarathon distance. However, they are still far away from the age of peak ultramarathon performance which is generally achieved at ages older than 35 years (Cejka et al., 2014; Knechtle, Di Gangi, Rüst, Rosemann, & Nikolaidis, 2018; Nikolaidis & Knechtle, 2018). It is well-known that the age of peak performance in endurance sports increases with increasing length or duration of the endurance performance (Allen & Hopkins, 2015).

Boys were generally faster than girls, apart from European girls and girls from Oceania over the 50 km distance compared to boys from the same continent. This is an interesting finding as for adult ultramarathoners, men are generally faster than women in 50 km and 100 km races (Zingg et al., 2014). One possible explanation may be that there were only a small number of girls participating in the 50 km event, compared to larger number of participating boys and that girls may have been better trained and prepared for this particular event. In the 50-mile events boys were faster than girls, with a peak in average speed in the 1980s and a gradual decline thereafter. Male adult runners are faster than women across all mile races with distances ranging from 50 miles to 3100 miles (Zingg, Knechtle, Rosemann, & Rust, 2015). In adults, women, however, have closed the gap to men in the last decades (Peter, Rüst, Knechtle, Rosemann, & Lepers, 2014; Waldvogel et al., 2019; Zingg et al., 2014; Zingg et al., 2015), something that could not be observed among our group of young ultramarathon runners.

In 50 km races, running speed decreased in both girls and boys for all nationalities. In 50 miles and 100 km races, running speed increased and then decreased across calendar years. Taken together, these youth ultramarathoners were not able to improve their running performance in the last years although in some races (*e.g.*, 50 miles and 100 km races) in earlier years their running speed was higher than in the last years. *This decrease in speed may be due to the overall increasing participation, especially from less trained athletes, a phenomenon, that has been observed in adult ultramarathoners in 50 km* (Nikolaidis & Knechtle, 2018) and 100 km races (Knechtle, Di Gangi, et al., 2018). In addition, marathon races times have also become slower in the last years (Knechtle, Di Gangi, Rust, & Nikolaidis, 2019; Knechtle & Nikolaidis, 2018a; Nikolaidis, Rosemann, & Knechtle, 2018), *possibly for the same reason.*

277 *Performance analysis: Running speed by continent and distance*

278 The fastest male runners in the 50 km distance originated from Africa, followed by Europe  
279 and Oceania but participation numbers compared to European runners were very low. In girls  
280 the fastest runners came from Oceania followed by Europe and North America. As mentioned  
281 before, European and Oceanian girls were faster than their male counterparts. The 100km  
282 were mostly run by European boys and girls, however the fastest average speed was observed  
283 in Asian boys and girls. The 50 miles were mostly run by runners from North America. Elite  
284 adult ultramarathoners runners mostly originated from Japan (Nikolaidis, Onywera, &  
285 Knechtle, 2017), but no such classification system or record books existed in youth runners.

286 The increase of participation of youth ultra-runners raised questions about long-term health  
287 implications of these events and whether children should participate in these events at all  
288 (Scheer & Hoffman, 2018). Data from childhood participation in marathons suggested that  
289 there were no acute adverse health outcomes (Roberts, 2007); however, data on ultra-distance  
290 running in the youth athlete were currently not available and no consensus about guaranteed  
291 safe running distances exist (Roberts, 2007). The musculoskeletal system was of particular  
292 interest since it was immature during childhood and especially vulnerable for injuries at  
293 growth plates, tendon attachments, and/or articular cartilage at joint surfaces (Krabak, Snitily,  
294 & Milani, 2016). Other aspects to consider during maturation were brain development with  
295 enhancement of cognitive and psychological function, especially since ultra-endurance  
296 running could be an intense stressor on cognitive performance (Hurdiel et al., 2018), induce  
297 changes within the autonomic nervous system (Vieluf, Scheer, Hasija, Schreier, &  
298 Reinsberger, 2019) and impair rational decision-making processes in adults (Hoffman &  
299 Krouse, 2018). Examining the long-term health implications of childhood ultra-running would  
300 be an important area of future research and until such date would be available it might be

prudent to consider individual medical, physiological, biomechanical and psychological developments when recommending youth athletes to participate in ultra-running events.

### ***Limitations***

The DUV database was the largest ultra-running database worldwide, which has been widely used to gain insights into participation and performance trends (Knechtle et al., 2019; Knechtle & Nikolaidis, 2018b; Scheer & Hoffman, 2018); however, not all results may be completely accurate with any large dataset. The subset of DUV data was previously analysed and any questionable data cross checked with the ultrasignup.com database, another popular ultra-running result database, trying to eliminate any inaccuracies (Scheer & Hoffman, 2018).

Races with the same distance were grouped together for calculation of average speed. This was a limitation, as specific race characteristics with respect to running surface, elevation change, environmental conditions and level of support were not taken into consideration (Scheer et al., 2020). However, due to the retrospective character of the study, the multitude of different races across calendar years, calculation and comparisons of individual speeds for each race and calendar year was not feasible.

### **Conclusion**

In summary, participation in childhood and adolescent ultramarathon running was on the rise, with the majority of runners originating from Europe and North America. The 50 km and 100 km distances were the most popular and boys were overall faster than girls, with the fastest boys originating from Africa and Asia, and the fastest girls coming from Oceania and Asia, over the 50 km and 100 km, respectively.

## 323 REFERENCES

- 324 Allen, S. V., & Hopkins, W. G. (2015). Age of Peak Competitive Performance of Elite  
325 Athletes: A Systematic Review. *Sports Medicine*, 45(10), 1431-1441. doi:  
326 10.1007/s40279-015-0354-3
- 327 Cejka, N., Rüst, C. A., Lepers, R., Onywera, V., Rosemann, T., & Knechtle, B. (2014).  
328 Participation and performance trends in 100-km ultra-marathons worldwide. *Journal*  
329 *of Sports Sciences*, 32(4), 354-366. doi: 10.1080/02640414.2013.825729
- 330 Costa, R. J. S., Knechtle, B., Tarnopolsky, M., & Hoffman, M. D. (2019). Nutrition for  
331 ultramarathon running: Trail, track, and road. *International Journal of Sport Nutrition*  
332 *and Exercise Metabolism*, 29(2), 130-140. doi: 10.1123/ijsnem.2018-0255
- 333 da Fonseca-Engelhardt, K., Knechtle, B., Rüst, C. A., Knechtle, P., Lepers, R., & Rosemann,  
334 T. (2013). Participation and performance trends in ultra-endurance running races  
335 under extreme conditions - 'Spartathlon' versus 'Badwater'. *Extreme Physiology and*  
336 *Medicine*, 2(1). doi: 10.1186/2046-7648-2-15
- 337 Eichenberger, E., Knechtle, B., Rust, C. A., Rosemann, T., & Lepers, R. (2012). Age and sex  
338 interactions in mountain ultramarathon running - the Swiss Alpine Marathon. *Open*  
339 *Access J Sports Med*, 3, 73-80. doi: 10.2147/oajsm.s33836
- 340 Hoffman, M. D., & Krouse, R. (2018). Ultra-obligatory running among ultramarathon  
341 runners. *Res Sports Med*, 26(2), 211-221. doi: 10.1080/15438627.2018.1431533
- 342 Hurdiel, R., Riedy, S. M., Millet, G. P., Mauvieux, B., Peze, T., Elsworth-Edelsten, C., . . .  
343 Dupont, G. (2018). Cognitive performance and self-reported sleepiness are modulated  
344 by time-of-day during a mountain ultramarathon. *Res Sports Med*, 26(4), 482-489. doi:  
345 10.1080/15438627.2018.1492401
- 346 Knechtle, B., Di Gangi, S., Rüst, C. A., Rosemann, T., & Nikolaidis, P. T. (2018). Men's  
347 Participation and Performance in the Boston Marathon from 1897 to 2017.  
348 *International Journal of Sports Medicine*, 39(13), 1018-1027. doi: 10.1055/a-0660-  
349 0061
- 350 Knechtle, B., Di Gangi, S., Rust, C. A., & Nikolaidis, P. T. (2019). Performance Differences  
351 Between the Sexes in the Boston Marathon From 1972 to 2017. *J Strength Cond Res*.  
352 doi: 10.1519/jsc.0000000000002760
- 353 Knechtle, B., & Nikolaidis, P. T. (2018a). Physiology and pathophysiology in ultra-marathon  
354 running. *Frontiers in Physiology*, 9(JUN). doi: 10.3389/fphys.2018.00634
- 355 Knechtle, B., & Nikolaidis, P. T. (2018b). Sex- and age-related differences in half-marathon  
356 performance and competitiveness in the world's largest half-marathon - the  
357 GoteborgsVarvet. *Res Sports Med*, 26(1), 75-85. doi:  
358 10.1080/15438627.2017.1393749
- 359 Knechtle, B., Nikolaidis, P. T., & Valeri, F. (2018). Russians are the fastest 100-km ultra-  
360 marathoners in the world. *PLoS ONE*, 13(7). doi: 10.1371/journal.pone.0199701
- 361 Knechtle, B., Rüst, C. A., Rosemann, T., & Lepers, R. (2012). Age-related changes in 100-km  
362 ultra-marathon running performance. *Age*, 34(4), 1033-1045. doi: 10.1007/s11357-  
363 011-9290-9

364 Krabak, B. J., Snitily, B., & Milani, C. J. (2016). Running Injuries During Adolescence and  
 365 Childhood. *Phys Med Rehabil Clin N Am*, 27(1), 179-202. doi:  
 366 10.1016/j.pmr.2015.08.010

367 Nikolaidis, P. T., & Knechtle, B. (2018). Age of peak performance in 50-km ultramarathoners  
 368 - is it older than in marathoners? *Open Access J Sports Med*, 9, 37-45. doi:  
 369 10.2147/oajsm.s154816

370 Nikolaidis, P. T., Onywera, V. O., & Knechtle, B. (2017). Running performance, nationality,  
 371 sex, and age in the 10-km, half-marathon marathon, and the 100-km ultramarathon  
 372 IAAF 1999-2015. *J Strength Cond Res*, 31(8), 2189-2207.

373 Nikolaidis, P. T., Rosemann, T., & Knechtle, B. (2018). Sex differences in the age of peak  
 374 marathon race time. *Chinese Journal of Physiology*, 61(2), 85-91. doi:  
 375 10.4077/CJP.2018.BAG535

376 Nikolaidis, P.T., Cuk, I., Clemente-Suárez, V.J., Villiger, E., & Knechtle, B. (2020). Number  
 377 of finishers and performance of age group women and men in long-distance running:  
 378 comparison among 10km, half-marathon and marathon races in Oslo. *Res Sports Med*,  
 379 11:1-11. doi: 10.1080/15438627.2020.1726745. [Epub ahead of print]

380 Peter, L., Rüst, C. A., Knechtle, B., Rosemann, T., & Lepers, R. (2014). Sex differences in  
 381 24-hour ultra-marathon performance - A retrospective data analysis from 1977 to  
 382 2012. *Clinics*, 69(1), 38-46. doi: 10.6061/clinics/2014(01)06

383 Roberts, W. O. (2007). Can children and adolescents run marathons? *Sports Med*, 37(4-5),  
 384 299-301. doi: 10.2165/00007256-200737040-00007

385 Scheer, B. V., & Murray, D. A. (2015). Ultramarathon Running Injuries. In M. N. Doral & J.  
 386 Karlsson (Eds.), *Sports Injuries*. Berlin: Springer.

387 Scheer, V. (2019). Participation trends of ultra endurance events. *Sports Medicine and*  
 388 *Arthroscopy Review*, 27(1), 3-7. doi: 10.1097/JSA.0000000000000198

389 Scheer, V., Basset, P., Giovanelli, N., Vernillo, G., Millet, G. P., & Costa, R. J. S. (2020).  
 390 Defining Off-road Running: A Position Statement from the Ultra Sports Science  
 391 Foundation. *Int J Sports Med*(EFirst). doi: 10.1055/a-1096-0980

392 Scheer, V., & Hoffman, M. D. (2018). Should children be running ultramarathons? *Current*  
 393 *Sports Medicine Reports*, 17(9), 282-283. doi: 10.1249/JSR.0000000000000512

394 Scheer, V., & Hoffman, M. D. (2019). Too much too early? An analysis of worldwide  
 395 childhood ultramarathon participation and attrition in adulthood. *J Sports Med Phys*  
 396 *Fitness*, 59(8), 1363-1368. doi: 10.23736/s0022-4707.19.09495-7

397 Vieluf, S., Scheer, V., Hasija, T., Schreier, P. J., & Reinsberger, C. (2019). Multimodal  
 398 approach towards understanding the changes in the autonomic nervous system induced  
 399 by an ultramarathon. *Res Sports Med*, 1-10. doi: 10.1080/15438627.2019.1665522

400 Waldvogel, K. J., Nikolaidis, P. T., Di Gangi, S., Rosemann, T., & Knechtle, B. (2019).  
 401 Women reduce the performance difference to men with increasing age in ultra-  
 402 marathon running. *International Journal of Environmental Research and Public*  
 403 *Health*, 16(13). doi: 10.3390/ijerph16132377

404 Zingg, M., Rüst, C. A., Lepers, R., Rosemann, T., & Knechtle, B. (2013). Master runners  
 405 dominate 24-h ultramarathons worldwide-a retrospective data analysis from 1998 to  
 406 2011. *Extreme Physiology and Medicine*, 2(1). doi: 10.1186/2046-7648-2-21



407 Zingg, M. A., Karner-Rezek, K., Rosemann, T., Knechtle, B., Lepers, R., & Rüst, C. A.  
408 (2014). Will women outrun men in ultra-marathon road races from 50 km to 1,000  
409 km? *SpringerPlus*, 3(1). doi: 10.1186/2193-1801-3-97

410 Zingg, M. A., Knechtle, B., Rosemann, T., & Rust, C. A. (2015). Performance differences  
411 between sexes in 50-mile to 3,100-mile ultramarathons. *Open Access J Sports Med*, 6,  
412 7-21. doi: 10.2147/oajsm.s76490

**Table 1-** Ultramarathon performance – speed km/h by distance. Mean (SD) and minimum (Min), maximum (Max) were reported.

Distance	Speed (km/h)			
	N	Mean (SD)	Min	Max
Distance				
50km	2083	7.78 (1.88)	1.75	15.46
50mi	958	7.39 (1.50)	1.73	14.08
100km	2057	5.95 (1.52)	3.18	14.52
10mi	81	5.79 (1.26)	2.65	9.96

**Table 2.** Mean and (SD) of ultramarathon performance speed in km/h. Distance races: 50 km, 50 mi and 100 km by sex, age and country (continent). Africa, Central-South America and Oceania, due to small sample size for 100 km races, were grouped together into “Other” group; for 50 mi the group “Other” included also Asia.

Distance		50 km, N=2083		50 mi, N=958		100 km, N=2057	
Age	Sex	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)
10 - 13	F	21	6.16 (1.45)	6	5.91 (2.31)	2	5.09 (0.98)
	M	143	7.25 (1.81)	54	6.80 (2.04)	25	7.05 (2.49)
14 - 15	F	56	7.06 (1.88)	15	6.39 (1.01)	5	5.51 (0.48)
	M	245	7.63 (1.66)	120	7.05 (1.46)	95	6.66 (1.72)
16 - 17	F	148	7.21 (1.58)	40	6.58 (1.00)	37	5.92 (1.44)
	M	675	7.98 (1.90)	364	7.44 (1.36)	435	6.09 (1.36)
18	F	174	7.38 (1.67)	47	6.82 (1.10)	88	5.86 (2.11)
	M	621	8.11 (1.97)	312	7.82 (1.49)	1370	5.84 (1.47)
Continent	Sex	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)
North-America	F	348	7.16 (1.60)	101	6.63 (1.17)	10	6.04 (1.18)
	M	1391	7.92 (1.74)	755	7.52 (1.54)	59	7.41 (2.01)
Africa	F	1	4.50	-	-	-	-
	M	13	9.22 (3.75)	-	-	-	-
Asia	F	16	6.18 (1.00)	-	-	7	6.23 (2.08)
	M	86	6.64 (2.18)	-	-	66	7.61 (1.53)
Central-South America	F	8	6.06 (1.04)	-	-	-	-
	M	33	6.89 (1.65)	-	-	-	-
Europe	F	19	8.86 (2.08)	1	5.44	110	5.70 (1.88)

	M	143 8.72 (2.52)	20 6.83 (1.67)	1793 5.83 (1.37)
Oceania	F	7 9.11 (1.78)	- -	- -
	M	18 8.44 (1.56)	- -	- -
Other	F	- -	6 6.57 (0.77)	5 8.16 (1.44)
	M	- -	75 7.33 (1.07)	7 10.54 (3.44)

---

435

436

437

438

439

440

441

442

443

444

445

446

447

448

449

450

451

452

453

454

455

**Table 3.** Mean and (SD) of ultramarathon performance speed in km/h. Distance races: 50 km, 50 mi and 100 km by calendar year groups.

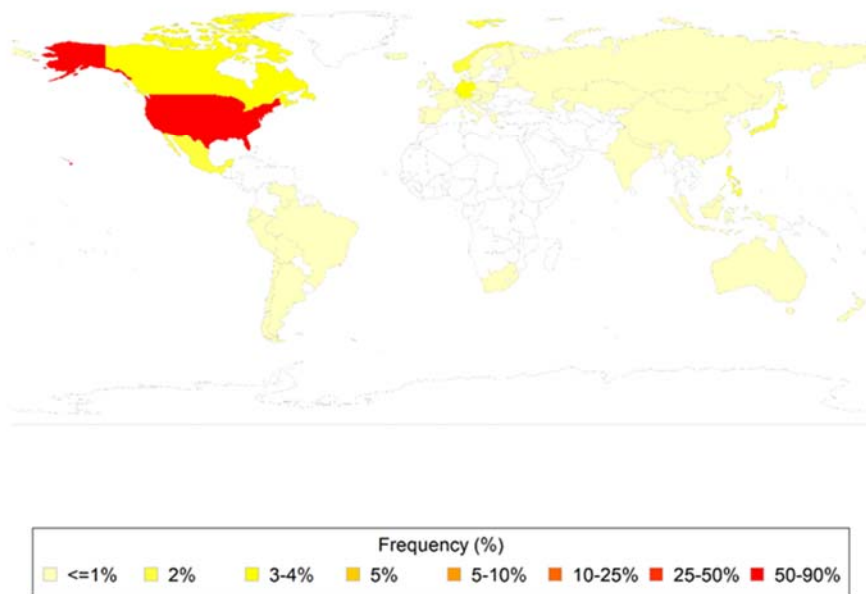
Distance		50 km, N=2083		50 mi, N=958		100 km, N=2057	
Year	Sex	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)
1960 - 1969	F	-	-	1	7.53	13	4.71 (0.59)
	M	-	-	12	6.39 (0.70)	259	5.13 (0.73)
1970 - 1979	F	-	-	4	6.98 (1.21)	45	5.29 (0.85)
	M	5	9.55 (1.62)	123	7.36 (1.41)	853	5.76 (1.10)
1980 - 1989	F	6	11.05 (1.74)	3	6.61 (0.79)	22	5.52 (0.91)
	M	44	9.90 (1.70)	102	8.15 (1.50)	464	6.29 (1.53)
1990 - 1999	F	21	8.04 (1.78)	15	6.95 (0.86)	13	9.21 (2.95)
	M	70	9.17 (2.26)	76	7.56 (1.39)	83	7.06 (2.33)
2000 - 2009	F	60	7.28 (1.35)	16	7.04 (0.98)	15	5.40 (2.02)
	M	343	8.25 (1.70)	155	7.64 (1.55)	98	6.50 (2.01)
2010 - 2018	F	312	7.06 (1.62)	69	6.42 (1.23)	24	6.27 (1.64)
	M	1222	7.67 (1.86)	382	7.31 (1.50)	168	6.41 (2.15)

## Figure legends

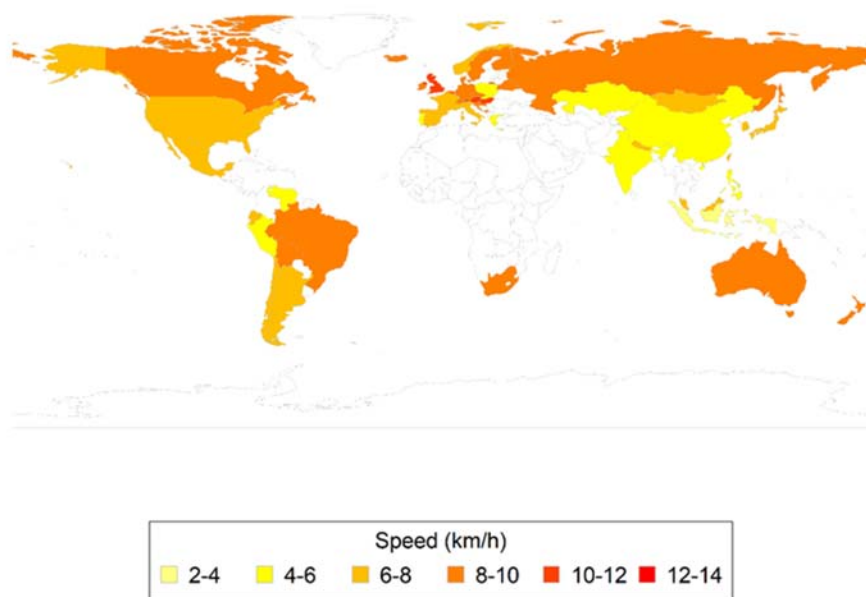
**Figure 1** Participation (%) and average performance (km/h) by nationality in 50-km races.

**Figure 2** Running speed by age groups and continent in 50-km races. Fitted values=line  
Points=mean of observed values.

### Country participation in 50 km

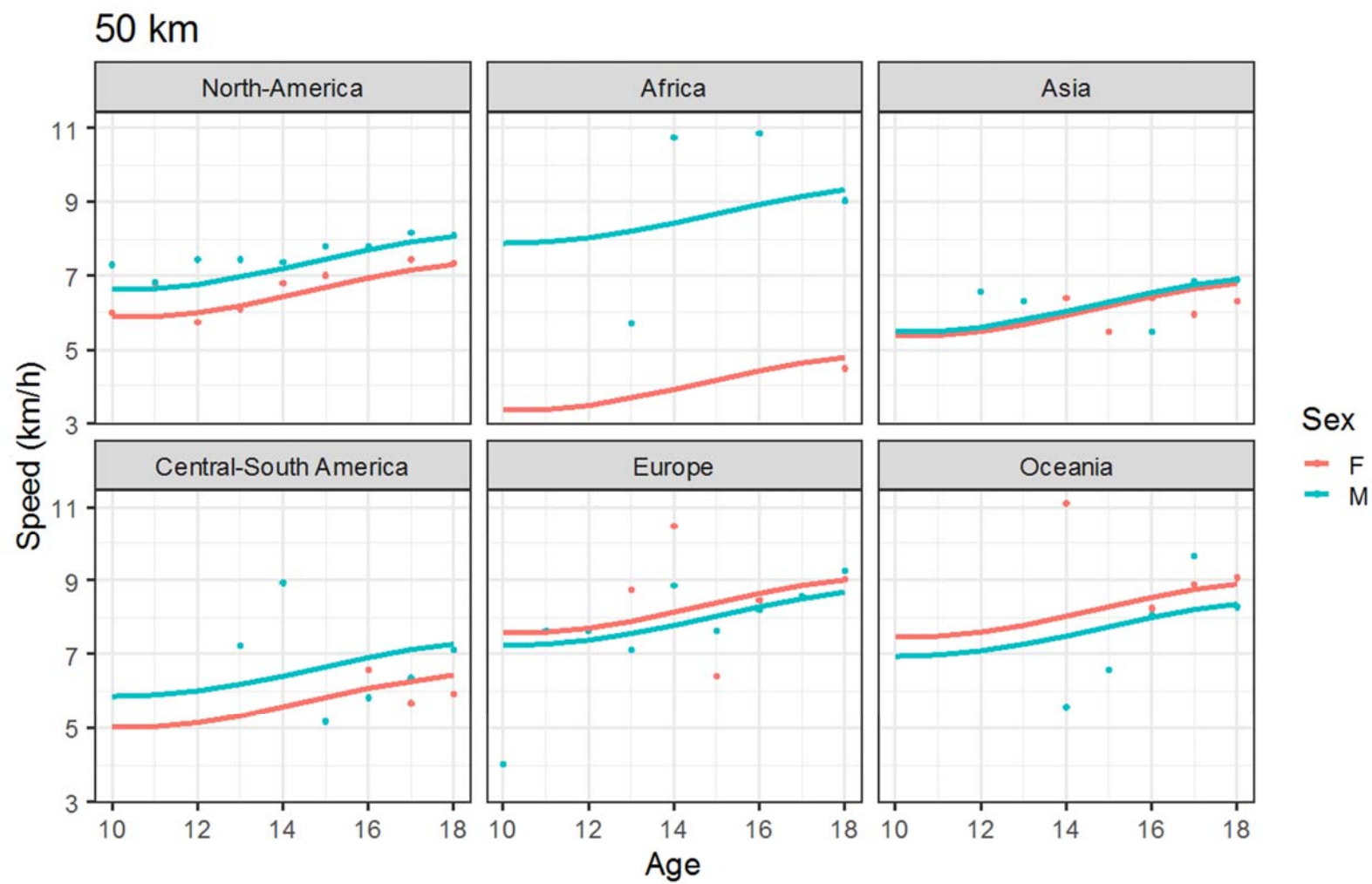


### Country performance in 50 km



485

486 **Figure 1**



487

488 **Figure 2**



## Supplementary material

**Table S1.** Regression analysis (mixed model) of ultramarathon (50 km, 50 miles and 100 km). Estimates and standard errors (SE) of fixed effects are reported. P-values ranges are marked with asterisks (see note). Smoothing terms, basis splines (BS), are denoted with BS(x) t, where x=year, age; t=1,2,3. In 50 km, we considered observations from 1980 onward.

	Distance-limited races		
	50 km	50 miles	100 km
<b>Age effect</b>			
BS(Age)1	-0.130 (0.616)	0.293 (0.925)	
BS(Age)2	1.092** (0.336)	0.839 (0.477)	
BS(Age)3	1.414*** (0.325)	1.717*** (0.512)	
Age			0.033 (0.025)
<b>Year effect</b>			
BS(Year)1	-1.341 (0.867)	3.319*** (0.955)	1.043* (0.523)
BS(Year)2	-2.255*** (0.427)	0.911* (0.372)	3.796*** (0.329)
BS(Year)3	-2.829*** (0.418)	0.843 (0.461)	0.116 (0.317)
<b>Continent effect(ref. North-America)</b>			
Asia	-0.513 (0.535)		0.246 (0.254)
Africa	-2.527 (1.750)		
Central-South America	-0.872 (0.659)		
Europe	1.695*** (0.424)	-0.705* (0.302)	1.497*** (0.211)
Oceania	1.586 (0.839)		
Other		0.286 (0.171)	1.944*** (0.528)
<b>Sex effect</b>			

Sex = M (ref=F)	0.762*** (0.121)	0.776*** (0.152)	0.455*** (0.132)
<b>Interaction effect</b> Sex: Continent			
M: Africa	3.767* (1.823)		
M: Asia	-0.644 (0.575)		
M: Central-South America	0.087 (0.730)		
M: Europe	-1.100* (0.454)		
M: Oceania	-1.285 (0.958)		
Constant	8.394*** (0.510)	4.127*** (0.665)	5.166*** (0.531)
Observations	2078	958	2057
Runners	1491	765	1815
<i>Note:</i>	*p<0.05 **p<0.01 ***p<0.001		

494

495

496

497

498

499

500

501

502

503

504

505

506

507 **Figure S1** Participation (%) and average performance (km/h) by nationality in 50 miles  
508 races.

509 **Figure S2** Participation (%) and average performance (km/h) by nationality in 100-km  
510 races.

511 **Figure S3** Running speed across years and continent in 50-km races. Fitted values=line.  
512 Points=mean of observed values.

513 **Figure S4** Running speed by age groups and continent in 50-miles races. Fitted  
514 values=line. Points=mean of observed values.

515 **Figure S5** Running speed across years and continent in 50-miles races. Fitted values=line.  
516 Points=mean of observed values.

517 **Figure S6** Running speed by age groups and continent in 100-km races. Fitted  
518 values=line. Points=mean of observed values.

519 **Figure S7** Running speed across years and continent in 100-km races. Fitted values=line.  
520 Points=mean of observed values.

521

522

523

524

525

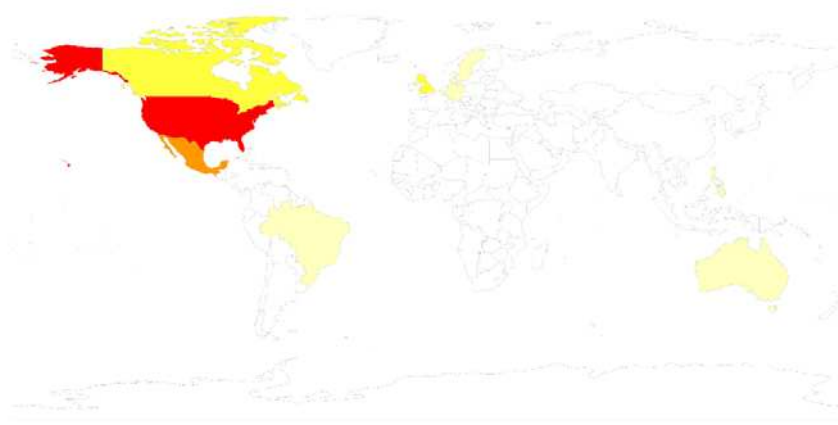
526

527

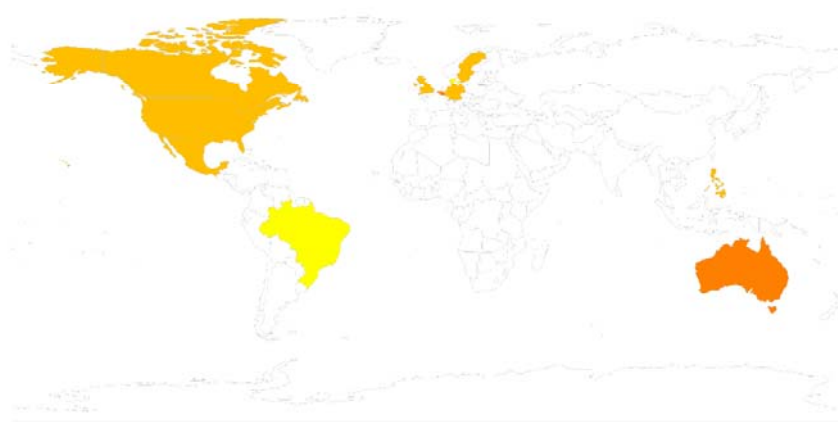
528

529

### Country participation in 50 miles



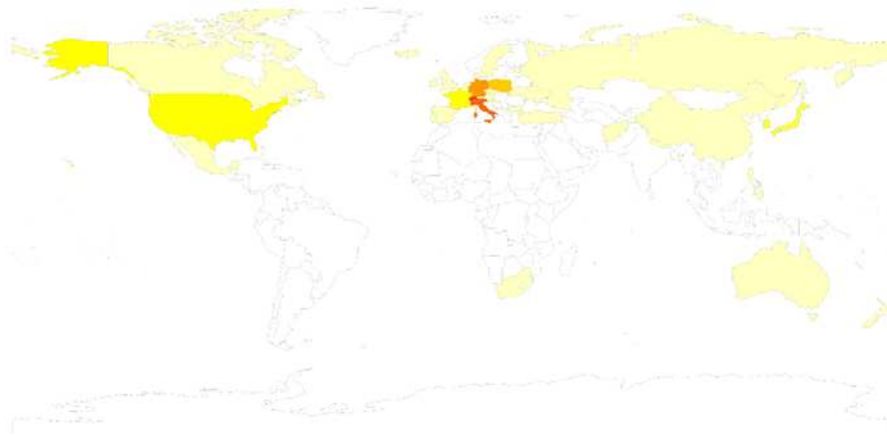
### Country performance in 50 miles



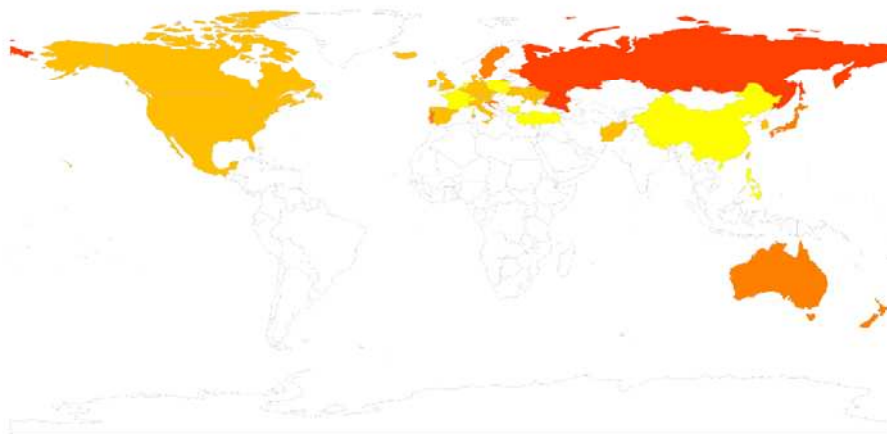
555

556 **Figure S1**

## Country participation in 100 km

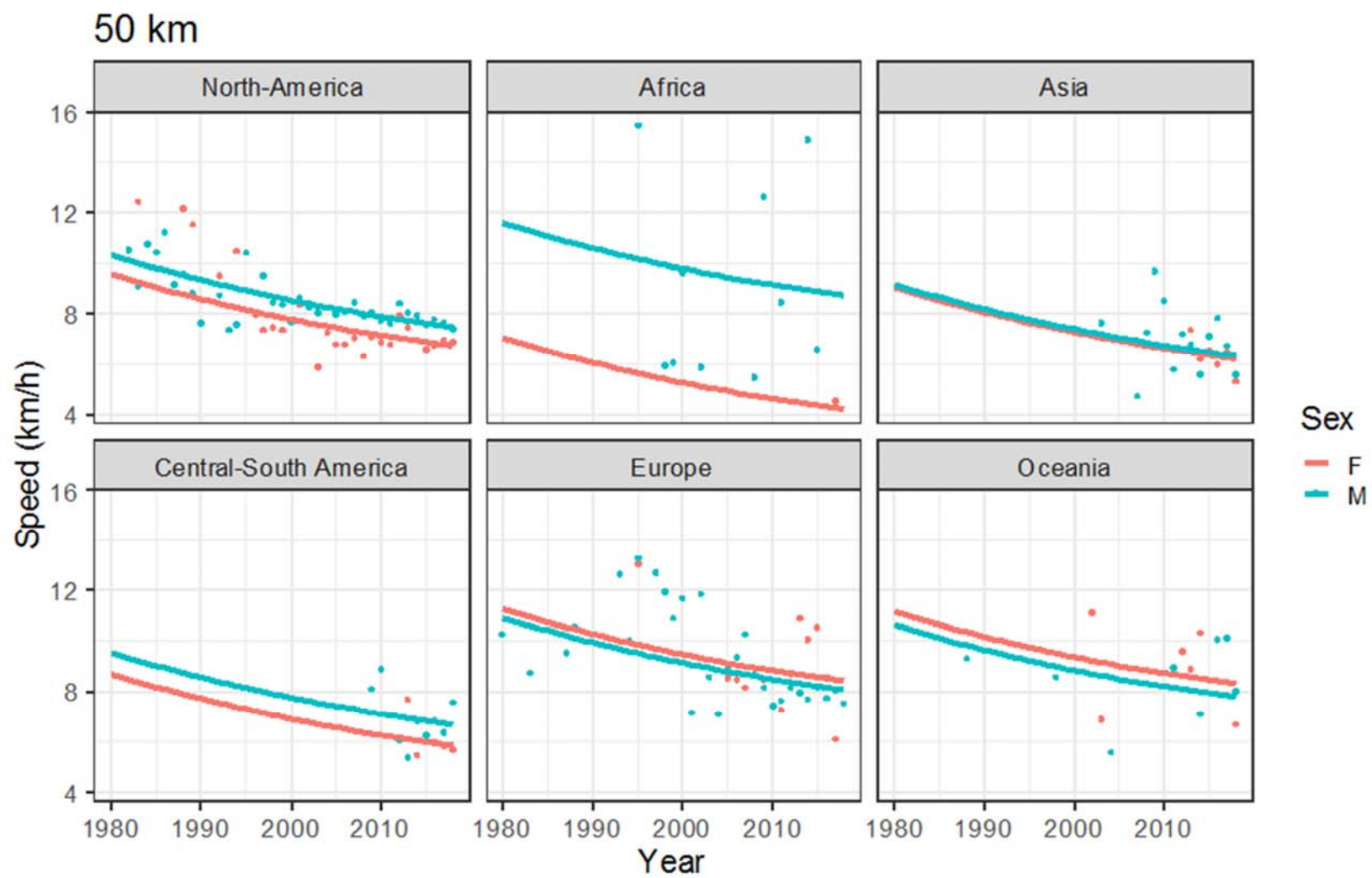


## Country performance in 100 km



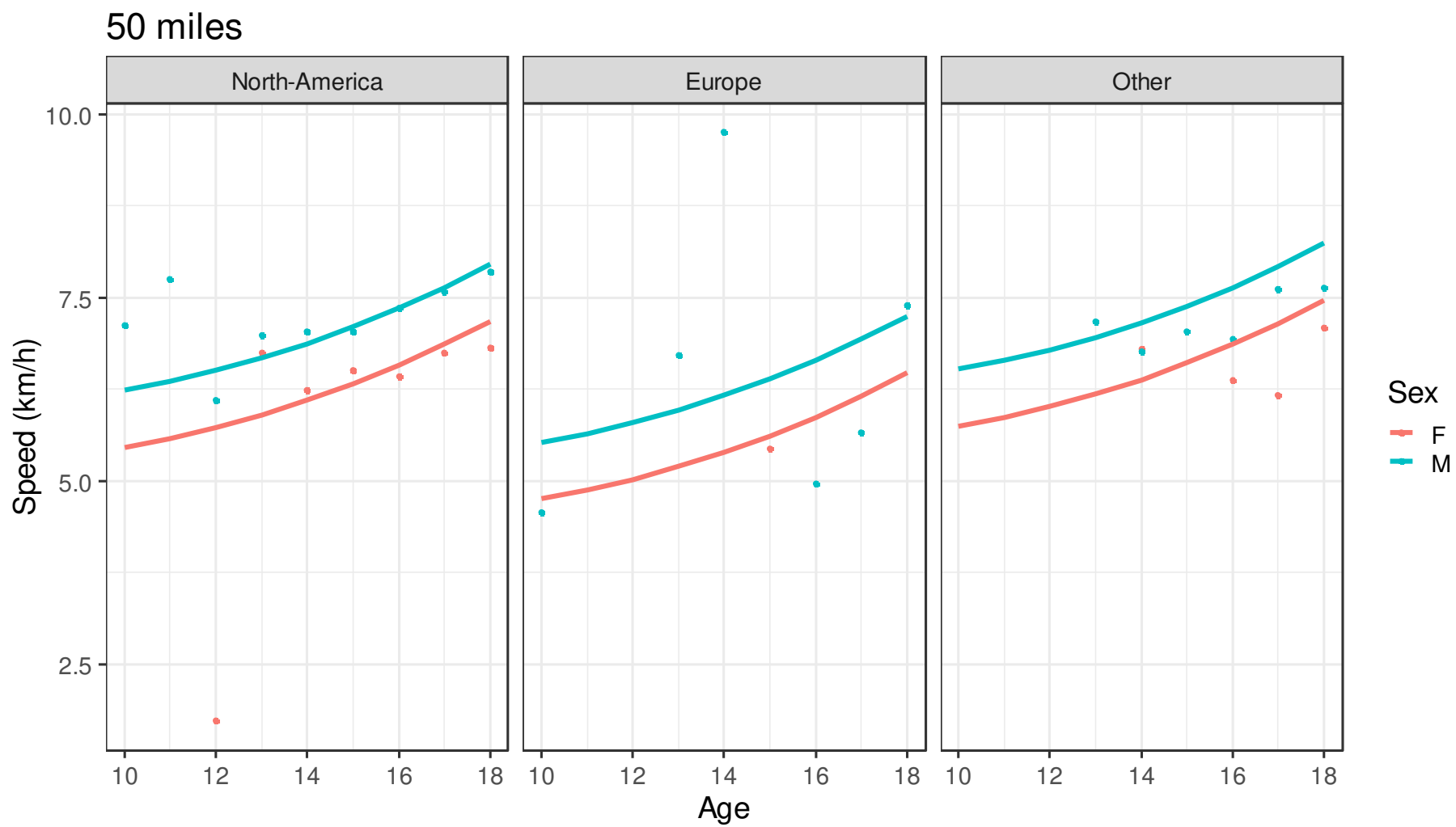
557

558 **Figure S2**



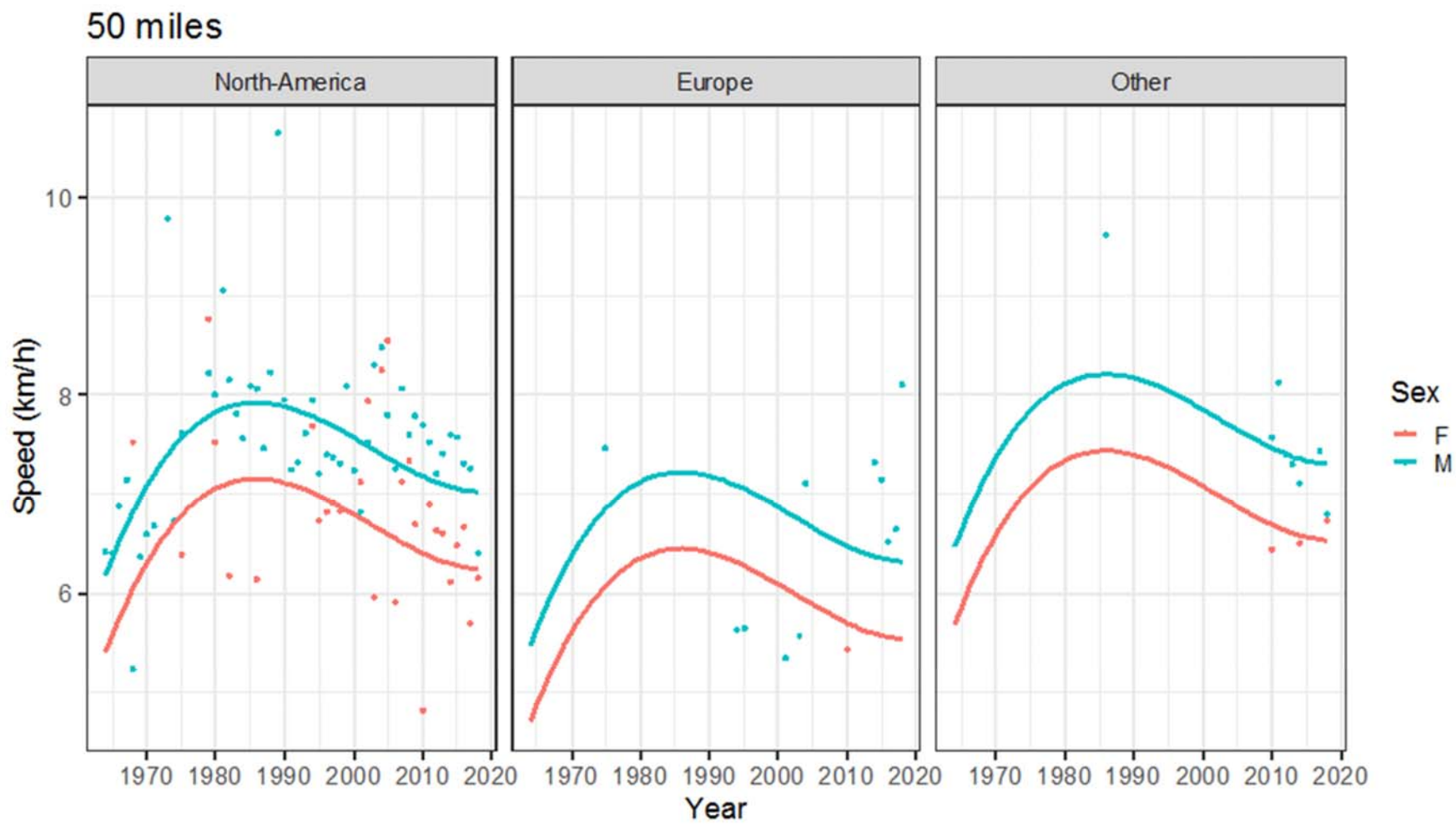
559

560 **Figure S3**



561

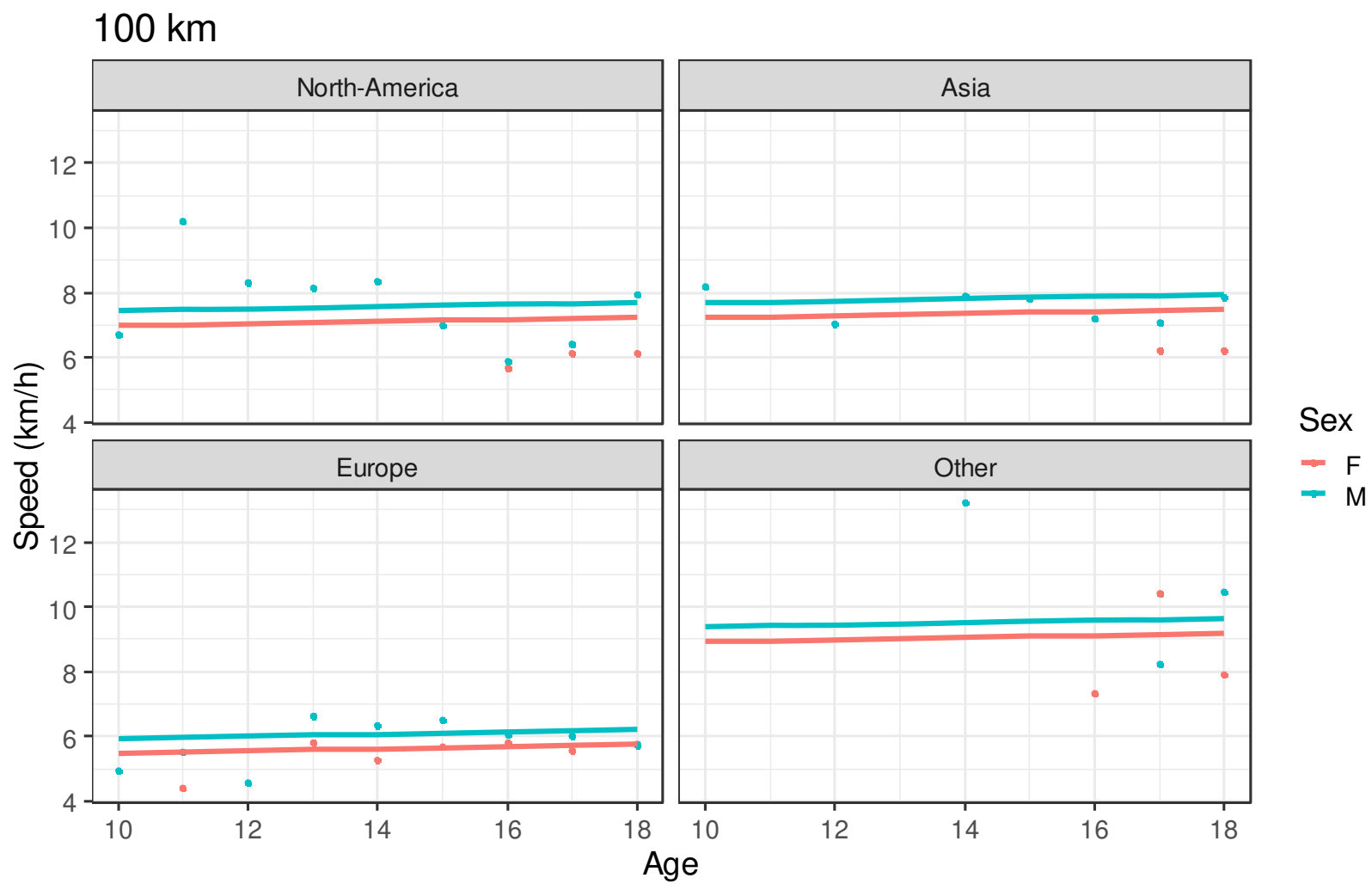
562 **Figure S4**



563

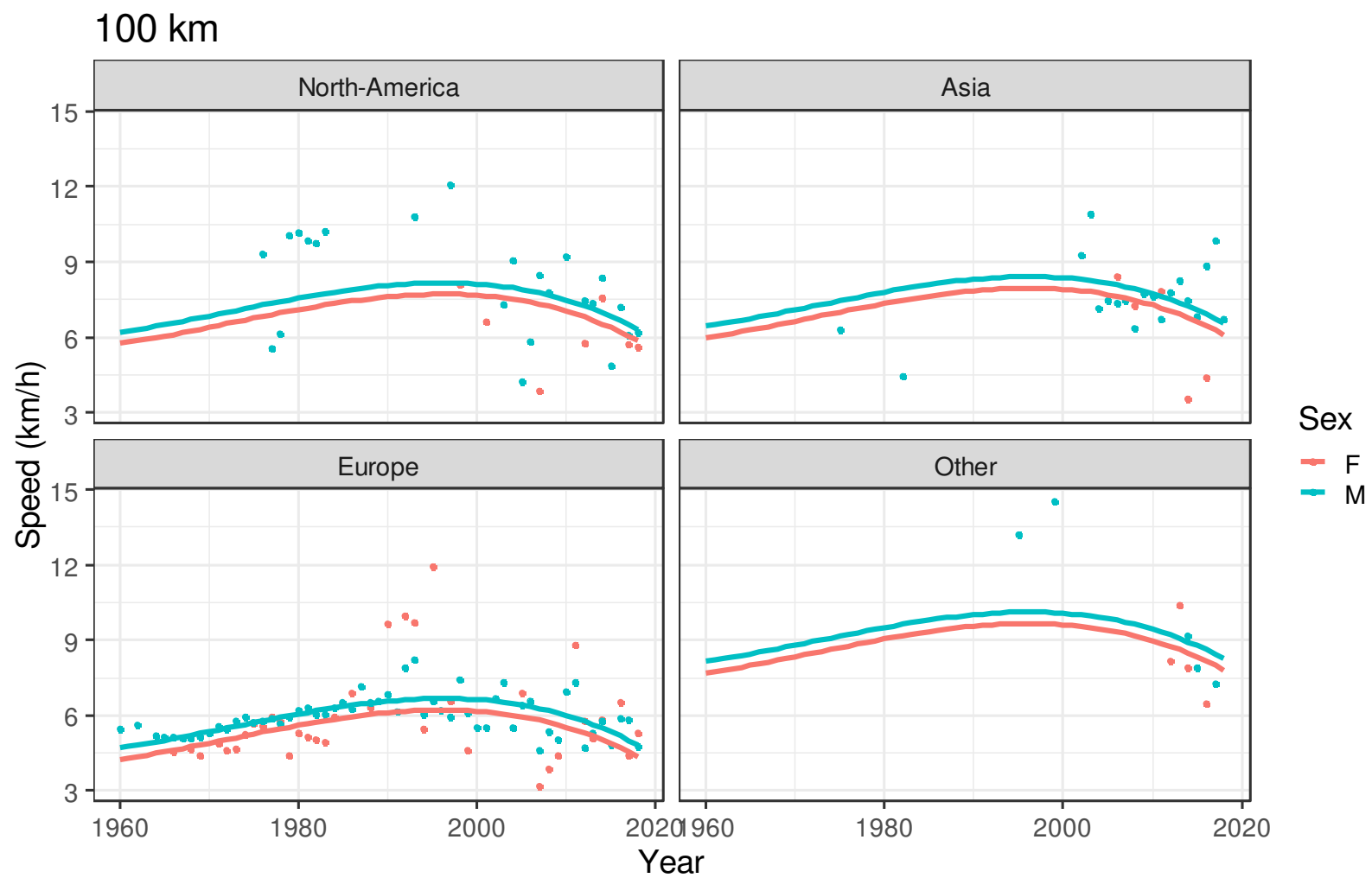
564 **FigureS5**





565

566 **Figure S6**



567

568 **Figure S7**